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ANISOTROPY OF FATIGUE STRENGTH IN BENDING AND IN TORSION OF A STEEL AND TWO ALUMINUM ALLOYS

by

W. N. Findley and P. N. Mathur

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UNIVERSITY OF ILLINOIS

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The Effect of Different States of Stress on the Fatigue of Materials
with Corrections for Anisotropy; and the Basic Laws
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ANISOTROPY OF FATIGUE STRENGTH IN BENDING AND IN TORSION OF A STEEL AND TWO ALUMINUM ALLOYS.

by

W. N. Findley* and P. N. Mathur**

SUMMARY

An investigation of anisotropy in fatigue, under two different states of stress, bending and torsion, was made of two aluminum alloys and a steel. A somewhat similar trend was observed in the variation of the fatigue strengths with orientation relative to the texture, for all three metals.

The fatigue strength in bending decreased as the orientation changed from longitudinal to diagonal to transverse; and the fatigue strength in torsion was nearly constant at all three orientations.

The results of the tests are explainable from the concept that cyclic principal shear is primarily the cause of fatigue but the ability of the anisotropic materials to withstand this action of cyclic shear stress is influenced by the magnitude and the direction of the complementary normal stress acting on planes of principal shear stress.

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Since the anisotropy was observed to be different for the two states of stress, bending and torsion, the combined stress theories of fatigue failure, based on linear superposition of the stress fields in bending and torsion, warrant a correction for anisotropy.

INTRODUCTION

The importance of anisotropy as a factor influencing the fatigue strength of metals under combined stress has been recognized in the previous papers (1,2,3)* on combined stress fatigue but data has not been available. In order to remedy this lack, the present tests for anisotropy were undertaken.

To properly interpret the laboratory data on fatigue under combined stress an understanding of anisotropy of the fatigue properties of metals and the relation of anisotropy to the impressed state of stress is desirable. A knowledge of directional properties of the material is also required in the design of many machine parts subjected to maximum stresses that are not necessarily in the direction of maximum strength of the material.

Previous work: Most fatigue studies for anisotropy reported in the literature have been concerned with fatigue tests made in bending on specimens cut parallel and perpendicular to the

* Numbers in parentheses refer to the bibliography at the end of the paper.

direction of the grain of the stock. The anisotropy was indicated by the comparative fatigue strengths (or percent variation) in the two directions.

A survey of the results of these fatigue investigations indicates a varying degree of anisotropy in different steels and aluminum alloys. (See Table I).

A very high degree of anisotropy was observed in several studies; particularly those on SAE 4340 steel forgings (4,5,6), on heat treated steels (7), and on different Ni, Ni - Cr steels (8,9,10).

Fatigue tests of aluminum alloys (11,12) indicate high anisotropy in aluminum alloys. Other investigators (13,14,15) studying different steels and aluminum alloys reported very little or no evidence of anisotropy.

In the tests of similar nature the influence on the anisotropy of variables such as the degree of forging reduction (16,17,18), location of the forged piece in the billet (16), stress gradient (notches) (16), etc. was observed. To the knowledge of the authors fatigue tests for anisotropy in torsion have been reported only in two instances. Von Rossing (19) reported results of fatigue tests on Cr - Mo and Ni - Cr - Mo steel forgings. His data indicated little or no anisotropy in torsional fatigue and rather pronounced anisotropy in bending fatigue.

Recently Ransom (6) reported results of torsion & bending fatigue tests for anisotropy of SAE 4340 steel forgings. He observed that most cracks initiated at inclusions for all orientations in torsion and only for transverse orientations in bending.

The literature on anisotropy of the static properties of metals have been reviewed in detail by Barrett (20).

Purpose and scope of the investigation: The present study was begun in September 1950 to investigate the influence of anisotropy on the fatigue properties under two different states of stress for three materials used in an investigation of fatigue of metals under combined bending and torsion (1,2,3,21,22,23,24).

The investigations for anisotropy covered SAE 4340 steel and 76S-T61 and 25S-T6 aluminum alloys. Fatigue tests on these metals were conducted both in bending and torsion on miniature specimens, having their axes in longitudinal, diagonal and transverse directions relative to the axes of the one inch rolled bars from which the specimens for combined bending and torsion were prepared.

MATERIALS, SPECIMENS AND TEST PROCEDURE

Materials: The materials tested were 76S-T61 and 25S-T6 aluminum alloys and SAE 4340 steel quenched and tempered to a hardness of

Rockwell C 25. The materials were received in the form of one-inch diameter hot-rolled bars. Details of composition and heat treatment are given for the three materials in references (1), (2) and (21) respectively. The specimens from SAE 4340 steel were not subjected to the vacuum drawing operation employed in reference (21). This resulted in slightly higher hardness in the present specimens.

Preparation of specimens: All fatigue specimens were of the miniature type, 3/4" long, 3/32" minimum diameter and 3/16" radius as shown in Fig. 5 of reference (25). These specimens had a Neuber stress concentration factor in bending of 1.09 and in torsion 1.04. All specimens were polished dry with No. 1, 2/0 and 4/0 carborundum paper wound around a 1/4" diameter rotating spindle.

All static tensile specimens were of the miniature type and were prepared in the laboratory of the Aluminum Company of America in the manner described in reference (26).

The fatigue specimens of 76S-T61 aluminum alloy were cut from several rectangular blocks machined from the round bars. The radial orientations of the specimens were recorded and specimens were tested in sets, in so far as possible, so that at each stress a longitudinal, diagonal and transverse specimen were tested from the same block. The static tension

specimens were prepared with the same orientations from parts of larger fatigue specimens which had previously been tested.

Fatigue specimens of 25S-T6 aluminum alloy were all cut from one continuous bar because it had been observed in tension tests of this material that the surface roughened during yielding with an uneven "grain" size varying from small to large in alternate quadrants. Metallurgical examination and hardness measurements also indicated a variable grain size. All fatigue specimens with longitudinal, diagonal and transverse orientations, except six, were prepared from two slabs cut as close to the center of the bar as possible and parallel to the diameter of greatest hardness. The six specimens were oriented transverse to the bar and perpendicular to the slab.

Unfortunately this procedure was not followed in the static tension specimens. The specimens were machined from short ends of bars so that the radial orientation of the specimens is not known.

Fatigue and static tension specimens of SAE 4340 steel were prepared in the same manner as the 25S-T6 aluminum specimens except that the fatigue specimens were machined from several short ends of bars selected for uniform hardness. The radial orientation was not controlled.

Static Tests: The static tests on these materials were made at the Research Laboratory of the Aluminum Company of America on special equipment for static tensile tests of miniature specimens (26,27). For each material, duplicate tensile tests were made on .05 in. diameter specimens, having longitudinal, diagonal and transverse orientations. The details of these tests were described in a report by Babilon (28).

Metallurgical Tests: The photomicrographs of longitudinal sections were taken near the center of the bars of all three alloys. These photomicrographs are shown in Figure 1.

Fatigue Tests: The fatigue tests were conducted in constant amplitude-of-deflection type Krouse fatigue machines modified by a specially designed fixture (25). The details of the specimens, the fixture, the method of loading of specimens in bending and torsion, and the test procedure have been described in reference (25). Because the geometry of crack formation frequently permitted the machine to continue running after the specimen had fractured, specimens in torsion were inspected with a magnifying glass every 10 minutes to detect cracks. For bending tests a slight tensile load applied by a flexible coil spring solved the problem.

The diameter of each specimen was measured by means of

a shadowgraph. For bending, the diameter was measured in the plane of bending; for torsion specimens, this diameter was averaged with the diameter at right angles to it.

The procedure for determining the S-N diagrams of each material in bending and torsion at each orientation consisted in tests of series A and B as follows:

Series A. Tests were made of one or two specimens of each orientation at various stresses to determine the shape of the S-N curve.

Series B. Tests of several specimens of each orientation were made at one stress to determine a more definite value of the fatigue strength.

RESULTS

Static Tests: The results of tensile tests for anisotropy of all three metals are presented in Figure 2. The diagrams represent the variation in the mechanical properties with orientation θ relative to the texture (or axis of the parent bar). The details of the test results are described in a report by Babilon (28).

Metallurgical Tests: The microphotographs shown in Fig. 1 of the longitudinal sections near the center of the bars revealed the following:

25S-T6 Aluminum Alloy: This alloy had a uniform distribution of fragmented Al Cu Fe Mn inclusions and a few Cu Al globules in the direction of working. The inclusion content of this alloy was high.

76 S-T61 Aluminum Alloy: There were fewer inclusions than in the 25S-T6 alloy, mostly of Al Cu Fe and Al Cu Fe Mn forming an inclusion texture in the direction of working.

SAE 4340 Steel: The structure had a highly banded distribution of carbides in the direction of rolling. Microphotographs of an unetched surface revealed elongated plastic inclusions, less than 1/4 inch long at a magnification of 250 X, aligned along the same direction.

Fatigue Tests: The data obtained from fatigue tests described in the preceding sections is presented in the form of S-N diagrams in Figures 3,4,& 5.Data obtained from Series B tests are summarized in tables II and III. The data points in the S-N diagrams represent individual specimens of series A and stress versus the average log N of n specimens of series B, see Tables II and III.

The fatigue strengths in bending and torsion interpolated from the S-N curves at a given member of cycles are presented in Figure 2, together with the static properties, as a function of the orientation θ relative to the texture. For all three metals, the fatigue strength in bending decreased from longitudinal to diagonal to transverse, with the diagonal value nearly intermediate between the other two.

The fatigue strength in torsion did not change as much as in bending. It was the highest in the diagonal direction for two metals and highest in the longitudinal direction for 25S-T6 aluminum. In all three materials the fatigue strength in torsion of transverse specimens was the lowest.

While the data points in Fig. 2 are connected by straight lines for clarity of presentation it is recognized that curves are more likely relations since the diagrams in Fig. 2 are only one quadrant in a repeating pattern duplicated directly or in inverse in other quadrants, and abrupt changes in the relations with orientation are not likely.

There seems to be rather strong evidence that an endurance limit existed in the 76S-T61 aluminum alloy in bending as shown in Fig. 4. The only other evidence (29) known to the authors of an endurance limit in aluminum alloys indicated that the endurance limit of 75S-T6 was reached at about 10^8 cycles. In the present tests the endurance limit was reached at about 10^6 cycles.

The variations of the static and fatigue properties in the transverse direction expressed in percentage of the longitudinal values were as follows:

76S-T61 aluminum alloy: Bending fatigue strength - 17.0% torsion fatigue strength - 4.4%, tensile strength - 3.2% yield strength - 4.7% and percent elongation - 19.8%.

25S-T6 aluminum alloy: Bending fatigue strength - 11.0% torsion fatigue strength - 7.4%, tensile strength + 5.9%, yield strength + 14.5% and percent elongation - 31.3%.

SAE 4340 Steel: Bending fatigue strength - 12.0%, fatigue strength in torsion - 2.9%, tensile strength - 2.0%, yield strength - 3.2% and percent elongation - 25.4%.

The fatigue strength of 25S-T6 aluminum alloy in torsion for transverse specimens perpendicular to the plane of greatest strength (designated as the transverse-perpendicular orientation) was found to be about 6.6 percent less than the corresponding value in the plane of greatest strength.

In torsion tests of miniature specimens of the 25S-T6 aluminum alloy it was observed that the initial crack propagation appeared to be on longitudinal planes of the longitudinal specimens and along transverse planes of the transverse

specimens. This indicates a lower resistance to fatigue fracture in shear along planes containing the direction of the texture.

The fact that the tensile strength data for 25S-T6 aluminum alloy was higher transverse to the bar than longitudinal is difficult to explain. It may result from variations in tensile strength along different diameters in the bar as observed for fatigue strength.

In view of the different trends for bending and torsion fatigue strengths it would be of interest to have static torsion test data also to determine whether the strength in torsion is greatest in specimens oriented at 45°.

Size Effect

A comparison of the results of the present tests of longitudinal specimens in bending and torsion may be made with previous tests (1,2,21) of the same materials with larger diameter specimens, 0.26 in. diameter for 76S-T61 aluminum alloy and SAE 4340 steel and 0.30 in diameter for 25S-T6 aluminum alloy.

The present tests of 3/32 inch diameter specimens show both higher and lower fatigue strength than the larger specimens; the fatigue strength of 76S-T61 aluminum alloy at 2×10^5 cycles was 16 and 27 percent lower in bending and torsion respectively; the fatigue strength of 25S-T6 aluminum alloy at 5×10^5 cycles was 9 and 11 percent higher in bending

and torsion respectively; and the fatigue strength of SAE 4340 steel at 1.4×10^5 cycles was 23 and 14 percent higher in bending and torsion respectively.

The reasons for these differences are not apparent. The testing techniques for both tests of 76S-T61 aluminum alloy were the same and the technique employed for the larger specimens of the other two materials was not significantly different. The miniature specimens were taken as nearly as possible from the same position in the bar as the larger specimens, but the test section was as much as 1/8 inch farther from the center of the bar.

Ratio of Fatigue Strengths in Bending and Torsion:

Most theories of failure which have been considered for describing fatigue failure under combined stress require a constant value of the ratio of the fatigue strength in bending to that in torsion, see Table II of reference (22). Examination of the data for the three metals considered in the present report discloses the following values of the ratios of the fatigue strength in bending b to that in torsion t:

The values of b/t for the larger specimens, and the longitudinal, diagonal and transverse miniature specimens are respectively:

1.53, 1.75, 1.46, 1.43 for the 76S-T61 aluminum alloy;
1.67, 1.64, 1.65, 1.63 for the 25S-T6 aluminum alloy; and
1.48, 1.60, 1.49, 1.46 for the SAE 4340 steel.

These values are very consistent for 25S-T6 aluminum alloy; show considerable difference between materials; and indicate the highest value for miniature specimens of longitudinal orientation in two of the materials.

ANALYSIS AND INTERPRETATION OF RESULTS

The states of stress, bending and torsion, when applied to the three orientations, longitudinal, diagonal, and transverse, can be considered to represent six different states of stress on an element of anisotropic material. The fatigue data have been interpreted with the help of diagrams representing these elements in Figures 6 and 7.

Principal Stress Theory:

Fig. 6 shows the relationship between the direction of the principal stresses and the texture of the material (shown by the horizontal lines). If the greatest principal stress was the important factor in causing fatigue the following should be observed: (1) the fatigue strength in bending should decrease from longitudinal A to diagonal B to transverse C as observed in Fig. 2.; (2) the fatigue strength in torsion should be the same in longitudinal R and transverse T specimens (nearly true for two of the materials); (3) the ratio B/C of the fatigue strengths in bending for diagonal specimens to that

for transverse specimens should be the same as the ratios R/S or T/S of the fatigue strengths in torsion for longitudinal or transverse to that for diagonal specimens. This was not observed except for R/S in 25S-T6 aluminum alloy. Instead B/C $>$ 1 while R/S = T/S $<$ 1. Therefore, the greatest principal stress cannot be the stress factor which causes fatigue.

Principal Shear Stress Theory:

In Fig. 7 are shown the relationships between the directions of the principal shear stresses and the texture of the material. If the principal shear stresses were responsible for initiating fatigue failure the following should be observed: (1) the fatigue strength in torsion should be the same in the longitudinal R and transverse T specimens (nearly true for two of the materials); (2) the fatigue strength of the diagonal specimen in bending B expressed in terms of shearing stress should be the same as the torsion specimens R and T which was not true; (3) the fatigue strength in bending should be the same for longitudinal, A, and transverse, C, specimens, which was not observed; and (4) the fatigue strength in bending for specimens A and C expressed as shearing stress should equal the fatigue strength in torsion of the diagonal specimens, S. This also was not observed.

Principal Shear Stress plus Complementary Normal Stress Theory:

In Fig. 7 are also shown the normal stresses acting on planes of principal shear stress, here called "complementary normal stresses". If the factor primarily responsible for fatigue is cyclic shear stress and the ability of the material to withstand the action of the cyclic shear stress is influenced by the magnitude and sign of the complementary normal stress, the following should be observed: (1) the fatigue strengths in torsion, R and T, should be the same (nearly true for two of the three materials); (2) the fatigue strength in bending, expressed as shearing stress, for the diagonal specimen, B, should be less than the fatigue strengths R and T in torsion, as observed; (3) the fatigue strengths in bending expressed as shearing stress for specimens A and C should be less than the fatigue strength of the diagonal specimens, S, in torsion, as observed; and (4) the fact that the longitudinal fatigue strength is greater than the transverse may be explained by the aid of the two lowest diagrams in Fig. 7. In the longitudinal specimens the complementary normal stress would tend to open a crack between the metal and an inclusion (for example) while the principal shear stress would tend to close the crack. But, in the transverse specimen both complementary normal stress and principal shear stress tend to open a crack. Thus it would be expected that

the transverse specimen would be weaker.

The above analysis suggests that the principal stress and principal shear stress theories are not applicable, but that the theory of the principal shear stress plus the complementary normal stress may be applicable to fatigue.

INFLUENCE OF ANISOTROPY ON COMBINED STRESS FATIGUE

The results of the tests on all three materials indicate that the influence of anisotropy on the fatigue strength is considerably different for the two states of stress, bending and torsion.

The fatigue strength of these metals under combined bending and torsion will then be influenced by anisotropy. Its effect will depend on the relative magnitudes of the bending and torsional components of stress.

A theory predicting the fatigue strength of metals under combinations of two different states of stress like bending and torsion, therefore cannot be based on the linear superposition of the two stress fields without accounting for anisotropy.

In discussion of a previous paper (30) a method of correcting theories of failure for anisotropy was proposed for the special case of combined bending and torsion and

applied to data on fatigue under combined bending and torsion (1,2,3). Now that data on anisotropy of these same materials are available it is proposed for a later time to reexamine the correction for anisotropy, and the relations between theories of failure and the available test data.

CONCLUSIONS

(1) For all three materials, the fatigue strength in bending decreased as the orientation changed from longitudinal to diagonal to transverse direction. Similar trends were observed for tensile strengths and yield strengths of SAE 4340 steel and 76S-T61 aluminum alloy. For 25S-T6 aluminum alloy, this trend was reversed for tensile properties.

The variation in percent elongation (ductility) was consistent with the variations in bending fatigue in longitudinal and transverse directions but was inconsistent in the diagonal direction.

(2) The variation in the fatigue strength in torsion with direction of the working texture was smaller than in bending. For 76S-T61 aluminum alloy and SAE 4340 steel the fatigue strength in torsion was greatest in the diagonal orientation.

(3) Since the influence of anisotropy on the fatigue strength of metals was not independent of the state of stress in bending and torsion, the fatigue strength under combinations of the two stresses will be influenced by anisotropy. Consequently, the classical theories for combined stress fatigue based on linear superposition of stress fields in bending and torsion warrant a correction for anisotropy.

(4) The results of fatigue tests are explainable from the concept that the cyclic principal shear stress is primarily responsible for fatigue but the ability of anisotropic materials to withstand the action of cyclic shear stress is influenced by the magnitude and sign of the complementary normal stress.

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TABLE I REDUCTION IN FATIGUE STRENGTH FROM THE LONGITUDINAL TO TRANSVERSE DIRECTION

Metal	Reduction, Percent	Reference	Remarks
Ni- Steel	21.3	J. Pomey (16)	
Ni-Steel	45.0	" "	
Cr-Steel	13.1	" "	
Cr-Steel	16.65	" "	
Cr-Mo Steel	26.8	" "	
Ni-Cr Steel	40.0	" "	
Ni-Cr Steel	15.7	" "	
Ni-Cr Steel	37.3	Pomey and Ancella (3),(16)	Solid Specimens
Ni-Cr Steel	1.6	" " " " "	Notched Specimens
Steel	4.5	M. Perrin (16)	Location:Surface
"	14.5	" "	Between surface and center
"	17.5	" "	Center
Ni-Cr-Mo Steel	30.0	Von Rossing (19)	Location:Surface
" " " "	17.0	" "	Center
Cr-Mo-Steel	8.0	" "	Surface
" " "	2.5	" "	Center
Ni-Cr-Mo Steel	17.7	M. Lioret (16)	
Steel	15.0	Schmidt (17)	
Steel	7.0	" "	
Steel	11.4	" "	
Steel	28.5	" "	
Cr-Ni Steel	13.3	R. Mailander (10)	
Cr-Ni Steel	21.0	" "	
Cr-Ni Steel	22.0	" "	
Ni Steel	23.8	A. Junger (9)	
Duralumin	20.0	Berner and Kosten (11)	
SAE 4340 Steel	32.0	Ransom and Mehl (4),(5)	
Guntube Steels	16.0	" " " "	
SAE 4340 Steel	48.0	Ransom (6)	
Steel Forging	30.0	" "	
14S-T,24S-T al. alloys	30-35	Marin (12)	

TABLE II

FATIGUE DATA FOR ANISOTROPY OF SAE 4340 STEEL, RC25 (SERIES B)

LONGITUDINAL ORIENTATION

State of Stress	Stress, psi	Specimen	Cycles to Failure	Stress, psi	Specimen	Cycles to Failure	Stress, psi	Specimen	Cycles to Failure
Bending	110,000	1	65×10^3	94,000	1	223×10^3	90,000	1	744×10^3
		2	57		2	184		2	526
		3	98		3	283		3	237
					4	197		4	817
Average log N			4.8533			5.2974			5.7199
Torsion	65,000	1	56×10^3	55,400	1	363×10^3	52,000	1	352×10^3
		2	79		2	250		2	2,014
		3	172		3	325		3	1,473
					4	385		4	329
					5	822		5	3,103
Average log N			4.9604			5.3954			6.0056

TABLE II (Continued)

FATIGUE DATA FOR ANISOTROPY OF SAE 4340 STEEL, Rc25 (SERIES B)

DIAGONAL ORIENTATION

State of Stress	Stress, psi	Specimen	Cycles to Failure	Stress, psi	Specimen	Cycles to Failure	Stress, psi	Specimen	Cycles to Failure
Bending	110,000	1	50 x 10^3	94,000	1	157 x 10^3	90,000	1	198 x 10^3
		2	55		2	104		2	254
		3	47		3	264		3	192
		4	56		4	121		4	164
		5	52					5	177
Average log N			4.7151			5.1793			5.2895
Torsion	65,000	1	110 x 10^3	58,000	1	214 x 10^3	55,400	1	498 x 10^3
		2	125		2	425		2	755
		3	78		3	333		3	519
		4	69		4	157			
		5	288		5	152			
Average log N			5.0657			5.3718			5.7634

TABLE II (Continued)

FATIGUE DATA FOR ANISOTROPY OF SAE 4340 STEEL, Rc25 (SERIES B)

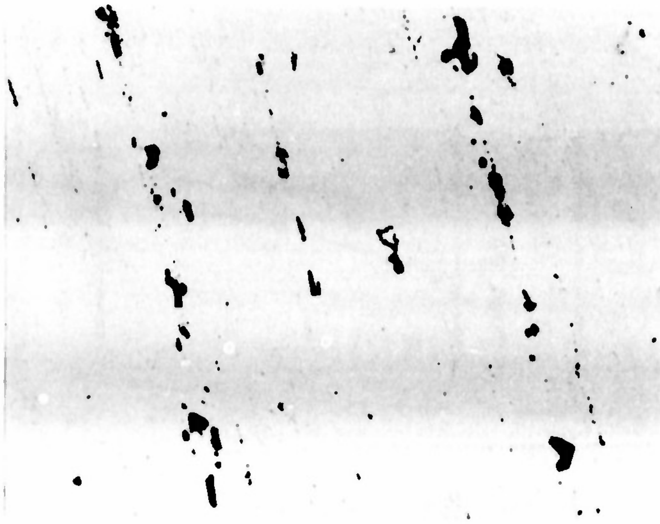
TRANSVERSE ORIENTATION

State of Stress	Stress, psi	Specimen	Cycles to Failure N	Stress, psi	Specimen	Cycles to Failure N	Stress, psi	Specimen	Cycles to Failure N
Bending	110,000	1	50×10^3	94,000	1	127×10^3	90,000	1	124×10^3
		2	28		2	127		2	107
		3	42		3	110		3	85
		4	33		4	175		4	86
		5	45		5	97		5	118
average log N			4.5899			5.0958			5.0117
Torsion	65,000	1	30×10^3	55,400	1	742×10^3	52,000	1	616×10^3
		2	54		2	262		2	1,978
		3	48		3	264		3	733
		4	42		4	676		4	1,394
		5	85		5	480		5	848
average log N			4.6887			5.5443			6.0047

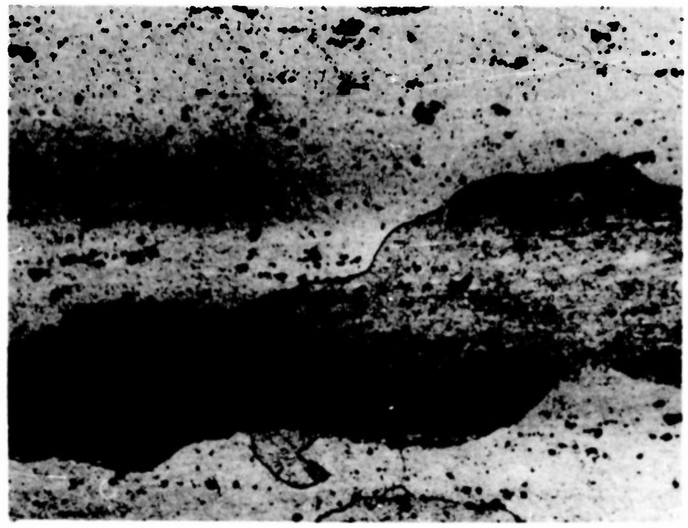
TABLE III

FATIGUE TESTS FOR ANISOTROPY OF 25S-T6 ALUMINUM ALLOY (SERIES B)

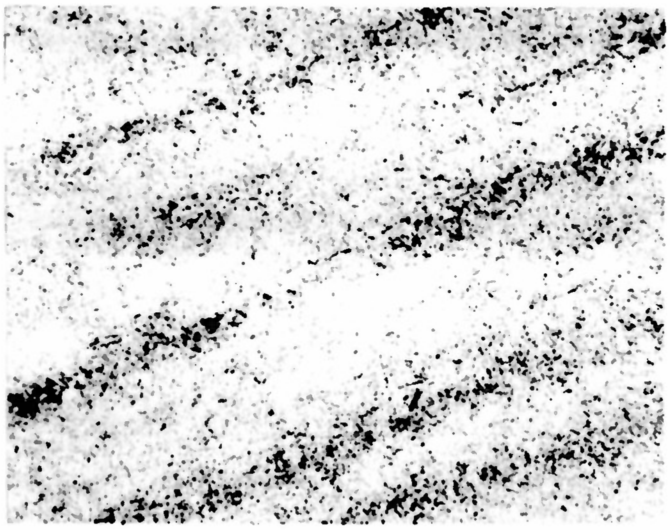
		ORIENTATION							
State of Stress	Stress, psi	LONGITUDINAL		DIAGONAL		TRANSVERSE		TRANSVERSE PERPENDICULAR	
		Specimen	Cycles to Failure N	Specimen	Cycles to Failure N	Specimen	Cycles to Failure N	Specimen	Cycles to Failure N
Bending	35,000	1	1,070 x 10^3	1	1,007 x 10^3	1	804 x 10^3		
		2	1,240	2	529	2	296		
		3	738	3	552	3	458		
		4	591	4	926	4	143		
		5	751	5	716	5	566		
		6	364	6	668	6	427		
		7	1,237	7	677	7	445		
Average log N			5.9036		5.8493		5.6035		
Torsion	25,000	1	127 x 10^3	1	142 x 10^3	1	113 x 10^3	1	14 x 10^3
		2	73	2	141	2	180	2	75
		3	234	3	223	3	117	3	51
		4	477	4	150	4	71	4	45
		5	467	5	104	5	75	5	106
		6	224	6	222	6	114	6	92
		7	259	7	69				
Average log N			5.3495		5.1469		5.0266		4.7285



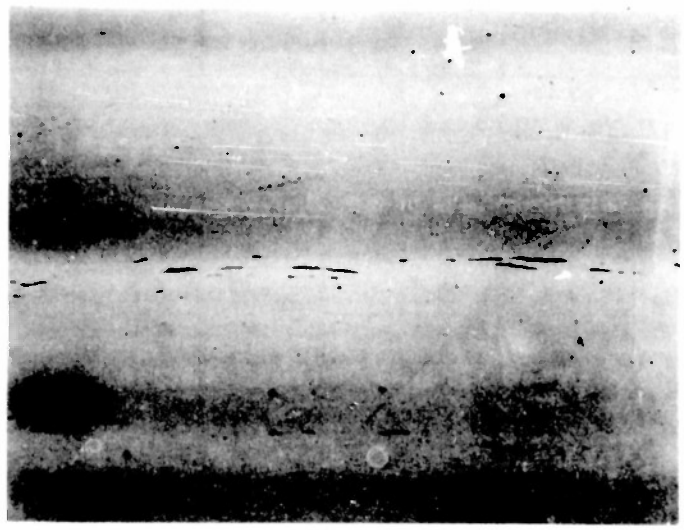
Microphotograph of 76S-T61
Aluminum Alloy (250X)



Microphotograph of 25S-T6
Aluminum Alloy (250X)



Microphotograph of SAE 4340
Steel (250X)



Microphotograph of SAE 4340
Steel Unetched (250X)

FIG. 1 MICROPHOTOGRAPHS SHOWING THE TEXTURE OF METALS PARALLEL TO THE AXIS OF THE ROLLED BARS.

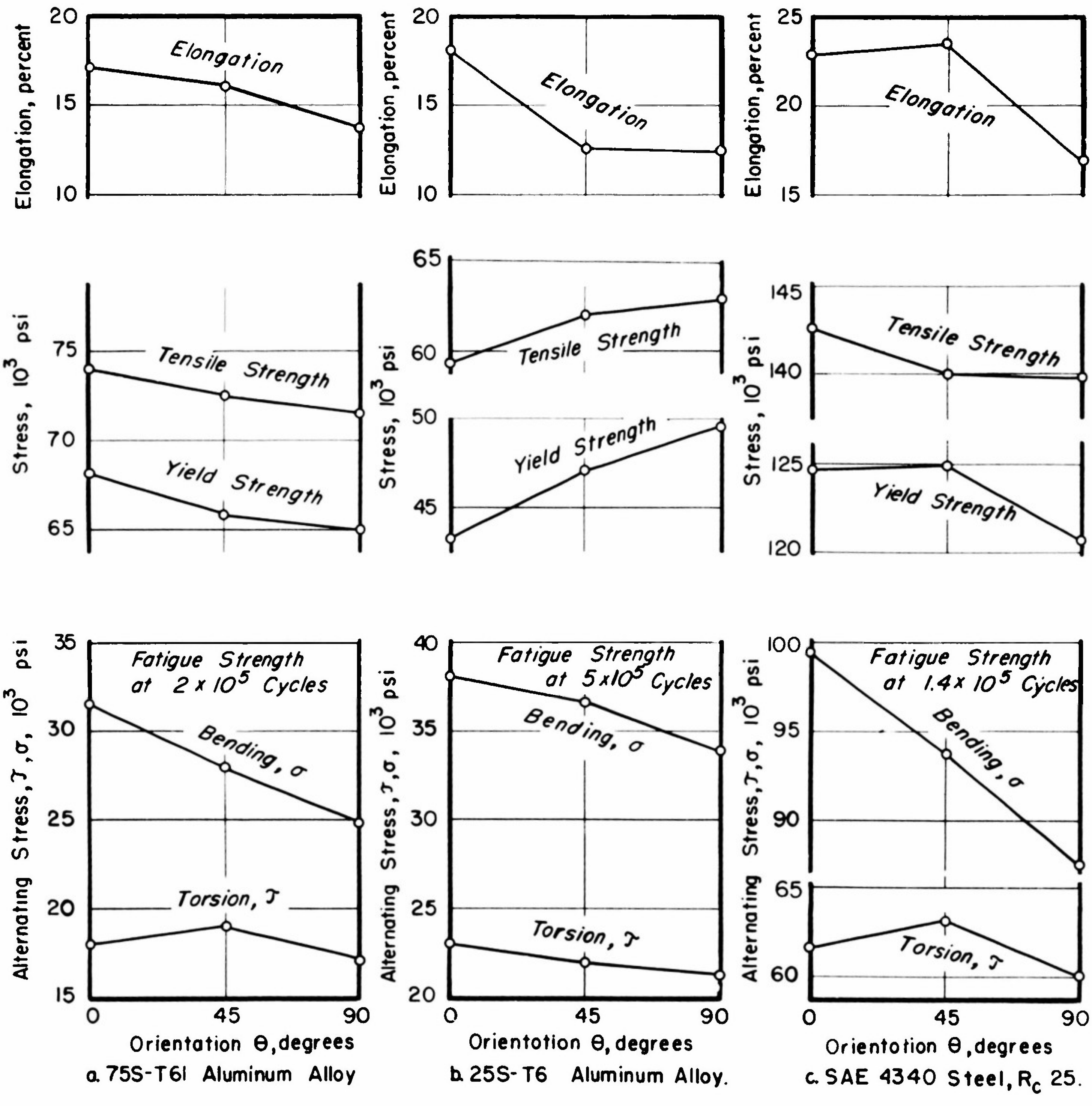


FIG. 2. VARIATION OF STATIC AND FATIGUE PROPERTIES WITH ORIENTATION θ RELATIVE TO TEXTURE.

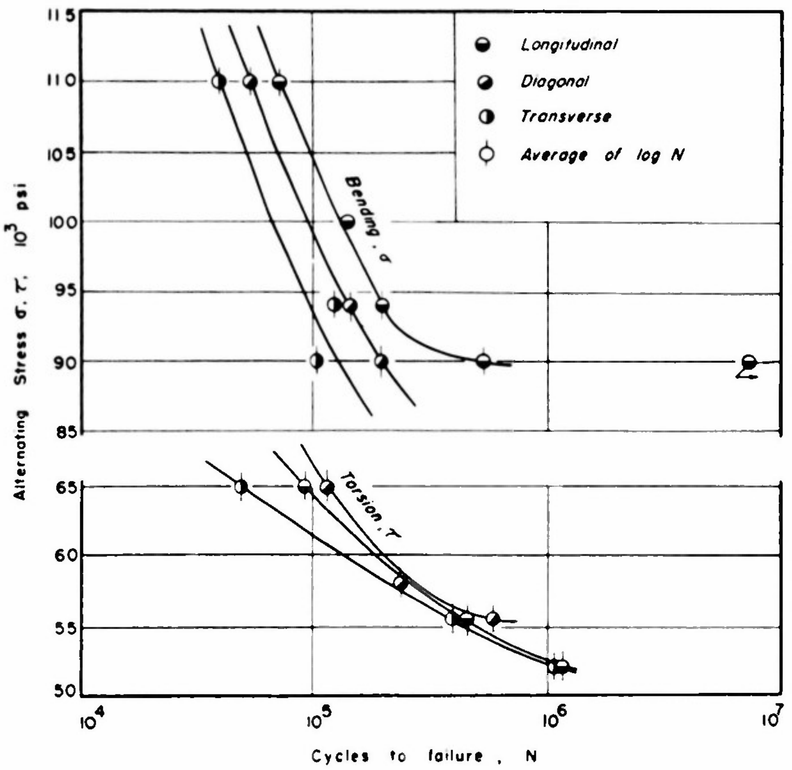


FIG. 3 FATIGUE TESTS OF SAE 4340 STEEL, Rc 25.

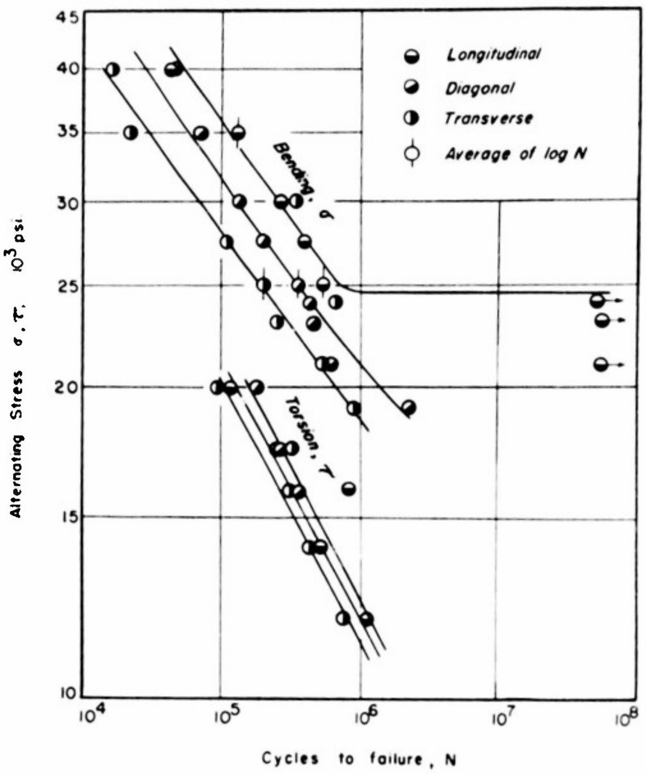


FIG. 4 FATIGUE TESTS OF 76S-T61 ALUMINUM ALLOY.

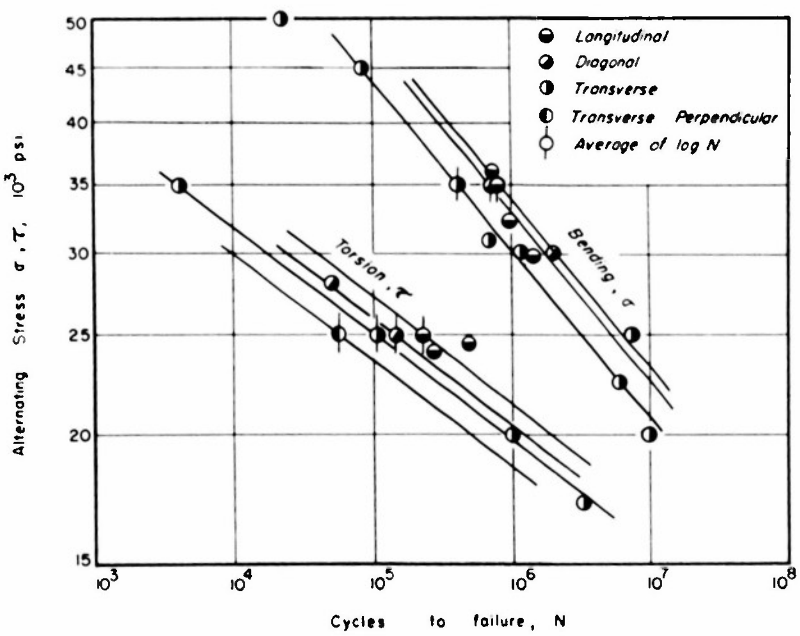


FIG. 5 FATIGUE TESTS OF 25S-T6 ALUMINUM ALLOY

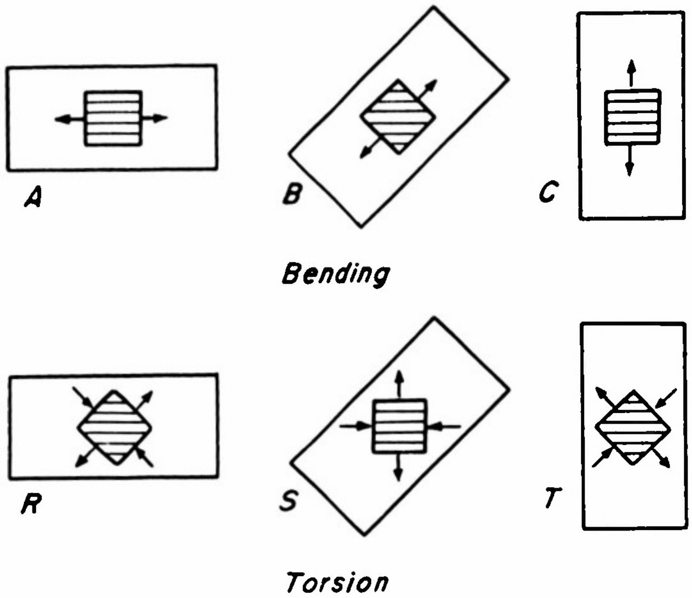


Fig. 6 Orientation of Principal Stresses Relative to the Texture of the Material in Tests for Anisotropy in the Fatigue Properties. (The direction of the texture is horizontal).

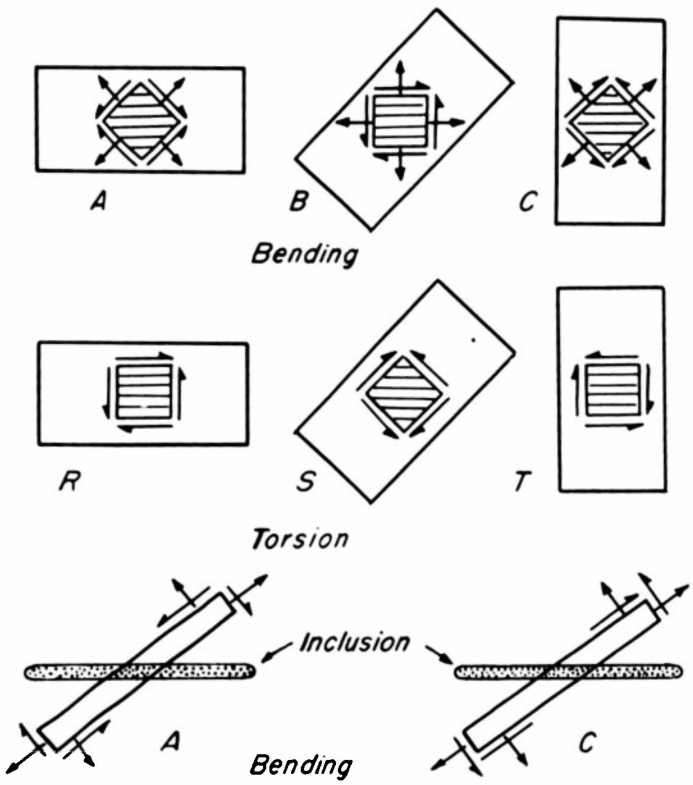


Fig. 7 Orientation of Principal Shear and Complimentary Normal Stresses Relative to the Texture of the Material in Tests for Anisotropy in the Fatigue Properties. (The direction of the texture is horizontal.)